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AN EVALUATION OF THE EFFECT OF ESTABLISHING A MINIMUM ECONOMIC ORDER QUANTITY (EOQ) ON THE AIR FORCE EOQ ITEM MANAGEMENT SYSTEM

THESIS

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AFIT/GLM/LSM/84S-14

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Preface

An Air Force Audit Agency report accused the Air Force Logistics Command (AFLC) of making poor policy decisions, and wasting millions of dollars. The report looked only at costs under theoretical conditions. This study resulted from AFLC's request for a more complete and realistic look at the effect of establishing a minimum buy quantity. This study provides policy makers with estimates of costs, benefits, and confounding factors that they can combine with their knowledge of intangible and political factors to select a policy that best meets national defense needs.

I used AFLC's EOQSIM simulation model and CREATE time sharing computer system to perform this study. Neither was very user friendly. Without the assistance provided by Doug Fleser, I would still be lost in the maze of the simulation model. The cryptic comments provided by the CREATE computer caused me confusion and consternation. A few words with Ira Saxton or Ray Yokell cleared up the confusion and transformed commotion into motion. The motion, however, wasn't always in the right direction. My advisor, Lt Col Palmer Smith, continually directed my efforts toward the end goal.

Both my wife Norma and I would like to thank the people who invented the home computer and modem. The inventors probably didn't realize the contribution they were making to a happier home life.

Thomas E. Disz

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Abstract

Policy decisions concerning the Air Force economic order quantity (EOQ) item management system affect thousands of items, billions of dollars, and the readiness of the Air Force. This study was initiated as a result of a March 1983 Air Force Audit Agency report finding potential waste of monies because of deviation from normal procurement cycle periods (PCPs). It evaluates different PCP policies and their affect on several system performance measures for the Air Force consumable item management system. The evaluation was performed using simulation models and actual Air Force item data. The results support the audit report showing increased cost and investment as a result of larger minimum PCPs. In the first year, larger minimum PCP policies require more stock fund dollars to fund inventory growth, approximately $1211M, $1311M, and $1560M for the 3, 6, and 12 month policies respectively. After the inventory reaches its new level the differences in the annual commit dollar requirements between policies becomes insignificant. The increased inventories cause the differences in implied costs between policies to become significant with larger PCPs having higher costs, approximately $547M, $570M, and $608M. The larger PCPs and larger inventories also result in larger

excesses. The customer support provided by the three policies is not significantly different, although larger PCPs produce more backorders during the transition to the new policy. Fewer procurement actions are required for larger minimum PCPs, approximately 61K, 56K and 46K respectively, although in the first year larger PCPs require a few more large buys. Fewer buys require less manpower and larger buys provide increased opportunity for quantity discounts. The choice of a "best" policy depends on the criteria of the policy maker and on political and practical considerations in addition to the factors discussed in this study.

AN EVALUATION OF THE EFFECT OF ESTABLISHING A MINIMUM ECONOMIC ORDER QUANTITY (EOQ) ON THE AIR FORCE EOQ ITEM MANAGEMENT SYSTEM

I. The Problem

Introduction

The Air Force manages 499,057 line items of consumable spares (4:1), referred to by the Air Force as Economic Order Quantity (EOQ) items and by the Department of Defense (DOD) as secondary items. The inventory value of these items is $4.3 billion dollars (4:1). The Department of Defense charges the Air Force with developing a policy to manage these items that will "minimize the total of variable order and holding costs subject to a time-weighted, essentiality-weighted requisitions short" (26:2). The Air Force Logistics Command (AFLC) has the responsibility for developing and carrying out the inventory policy for these items. With so many dollars involved a natural concern about the efficiency of the expenditure exists. Those concerned with the budget desire a reduction in costs without a consequent reduction in the support provided.

Problem Background

Upon its creation the Air Force inherited a primitive inventory management system. The amount to order was deter-

mined by summing operating requirements, stock level requirements, lead-time requirements and quantitative requirements. The estimated demand for the next fiscal year provided the operating requirement. An arbitrary number of days of stock to maintain at base and depot levels, determined by the category of the item, served as the stock level. The lead-time was an arbitrarily specified constant. Although not particularly efficient, the system worked with the technology then available. As technology advanced, operations research techniques improved and pressure to reduce costs increased, the inventory management system evolved into a more efficient system with a more scientific basis. The current management system is based on procedures developed by optimizing a mathematical model of the process. The overall effectiveness of this system or any system based on a model depends on how well the model reflects the real world and on how well the procedures implemented match those dictated by the model.

In March 1983 the Air Force Audit Agency (AFAA) released a draft Report of Audit of the AFLC procedures for managing consumable spares (1). The report identified several areas where the real world differed from model assumptions and several areas where the procedures dictated by the model were changed to facilitate implementation. The audit also contained estimates of the amounts of money wasted because of these deviations from the model. One

deviation made by AFLC was to establish a minimum buy quantity, minimum procurement cycle period (PCP), of six months. If the model indicated a three months supply (a 3 month PCP) as the most economical quantity to buy, AFLC would arbitrarily purchase a six month supply. AFLC implemented the policy because procurement could not process the number of purchases required by the DOD specified three month minimum. The AFAA audit stated the "system modifications were implemented without the benefit of economic analysis to determine cost benefit alternatives . . ." (1:Tab A, 6) and estimated "the increase from 3 months to 6 months has resulted in an increased average inventory investment of at least $90.6 million . . ." (1:Tab A, 7). As a result of these allegations AFLC initiated studies into several of the alleged problem areas. This thesis was initiated at AFLC's request for a study of the impact of changing the minimum procurement cycle period from three months to six months or twelve months.

Research Question

Is it in the best interest of the USAF to arbitrarily increase the minimum procurement cycle period from three months to six months or twelve months considering the uncertainty in demand forecasting, lead-time forecasting and cost factor estimating which provide the basis for the calculated procurement cycle period?

Investigative Questions

Determining if a policy is in the best interest of the USAF cannot be accomplished by evaluating only one performance measure. This system, as do most systems, has many goals and many measures of performance. The AFAA study evaluated only inventory cost. AFLC implemented the increased minimum PCP policy to resolve the practical problem of too many procurements. Proper evaluation of a policy requires evaluating all measures of system performance against all the current system goals. After reviewing the consumable items replenishment system and discussing the measures of system performance with people involved with the system, the following list of investigative questions was developed which, when answered, can be used to determine if increasing the minimum PCP policy serves the best interest of the USAF.

1. What is the effect of doubling the minimum procurement cycle period from three months to six months and again from six months to twelve months on:

   a. The value of the inventory?

   b. Number of procurement actions required?

   c. Portion of procurement actions requiring high value procedures?

   d. Stock fund dollars committed?

   e. Number of requisitions backordered?

   f. Number of items backordered?

   g. Value of items in long supply?

h. Percentage of EOQ's affected by the minimum PCP policy?

i. Implied system operating costs (holding, ordering, and backorder)?

2. What change in ordering (holding) cost would cause the procurement cycle period to be changed from three months to six months?

Question number two is proposed because some AFLC personnel maintained that inaccurate ordering and holding costs created more error than doubling the PCP. They further maintained that doubling the PCP compensated for these cost inaccuracies.

Questions Not To Be Considered

Establishing a minimum procurement cycle period involves more aspects of the total system than can be effectively addressed in this study. The three questions listed below deserve further research, but exceed the scope of this thesis.

1. A study of the behavior of items at the Defense Electronic Supply Center showed that items migrated back and forth between high and low demand categories (25). Do AFLC items tend to vacillate between high and low demand categories and if so how does this affect the desirability of increasing the minimum procurement cycle period?

2. Increasing the procurement cycle period should increase average inventory and therefore, stock availability. A change in the safety level formula should produce the same

increase in availability, at a lower cost. Will the change in safety level produce the increase at a lower cost as expected?

3. The items affected by changing the minimum PCP exhibit high annual dollar demand. Does the desirability of doubling the PCP depend on whether high unit cost or high annual demand is the basis for the high dollar demand?

II. Literature Review

Introduction

The validity of the Air Force EOQ item requirements determination system depends on the model used for system development, the relation of the model to the real world, and the degree of adherence to the procedures dictated by the model. This literature review will look at general inventory theory, summarize DOD guidance, describe the AFLC system, and identify the system's shortcomings in terms of EOQ theory.

General EOQ Theory

> Two fundamental questions that must be answered in controlling the inventory of any physical good are when to replenish the inventory and how much to order for replenishment [7:1].

The Wilson Lot Size Formula is the basic formula used to answer the how much to order question. A book by Hadley and Whitin (15) contains a detailed development of the formula and the assumptions necessary to develop the formula. The optimal operating doctrine and formula were developed "by minimizing the average annual cost" (15:30). The formula is:

$$Q = [(2DA)/IC]^{\frac{1}{2}} \qquad (1)$$

where Q is the economic order quantity in units, D is the annual demand in units, A is the cost of placing one order, and IC is the holding cost obtained by multiplying a holding

cost factor, I, by the unit cost, C (15:33). Establishing a reorder point that will have the order arrive just when the stock on hand runs out answers the when to order question. The reorder point "is the lead-time demand (i.e., the number of units demanded from the time an order is placed until it arrives) . . ." (15:33). For the basic Wilson model multiplying the lead-time in days by the daily demand during the lead-time produces the reorder point.

Many assumptions provide the basis for the basic Wilson formula. The validity of the application of the formula to the real world depends on how well the model assumptions reflect the real world. Below are listed the most significant assumptions. A discussion of how well they apply to the Air Force will be provided later.

1. The system is single echelon, single source (15:29).
2. An order is placed immediately when the reorder point is reached (15:161).
3. Demand is constant, known, and does not change over time (15:29).
4. Lead-time is constant and is independent of demand and the quantity ordered (15:29).
5. The optimal solution is one that will minimize average annual ordering and holding costs (15:30).
6. Cost to order is directly proportional to the number of orders placed (15:13).
7. Holding cost can be expressed as a fixed percentage of the average annual inventory (15:14).
8. Unit cost is constant (15:11).
9. The entire quantity ordered is received at one time (15:29).

Given these assumptions backorders will not exist. Backorders, however, do exist and several models have been developed to accommodate them. Hadley and Whitin (15:ch 4) and Presutti and Trepp (22) have developed models which adjust the answers to both the quantity to buy and when to buy questions. These models provide more complicated answers than the basic model, and most require specific probability distributions for demand and lead-time. They all have several characteristics in common. They consist of a basic reorder level, similar to the one for the basic Wilson formula, to which is added a safety level. Factors such as demand variability, lead-time, lead-time variability, holding costs and a backorder factor expressed in terms of cost or number of permissible backorders determine the size of the safety level. These models relax some of the assumptions, but create other problems such as determining the probability distributions of demand and lead-time and determining acceptable backorder factors.

DOD Guidance

The Department of Defense in DODI 4140.39 (26) provides guidance for use by the services and the Defense Logistics Agency (DLA) in developing procedures "for determining procurement cycles and safety levels of supply at Inventory Control Points (ICP's) for non-reparable secondary items . . ." (26:1). The basic policy requires minimizing ordering and holding costs subject to a constraint on back-

orders. DOD provides a basic model for total cost but does not specify a specific solution. The basic model is the same as the Wilson model with the addition of a complex backorder term. The ordering cost term is a function of the cost of placing one order and the number of orders per year. The holding cost term is a function of average inventory, unit cost, and a holding cost factor which represents the cost of holding one item in inventory for one year expressed as a percent of item unit cost. The third term is the shortage, backorder, or safety level term. This term is based on an essentiality factor, the number of units per requisition, the demand distribution, and an implied shortage parameter.

The instructions contain specific procedures on how to determine some of these factors but leave it to the agencies to develop others. DOD provides specific procedures for developing holding and ordering costs (26:encl 3, encl 4). Requisition size and demand depend on the specific items involved. Average inventory and number of orders depend on the preceding factors and the solution to the total cost model chosen by the agency. The essentiality factor provides a means to reflect the relative importance of each item. The agencies can use this factor if they desire. The final item is the implied shortage factor. Theoretically, it represents the cost of one requisition backordered for one year, but, in practice, it permits management to manipu-

late the cost and performance of the system to meet current constraints.

DOD recognizes that occasionally some problems occur when putting theory into practice. Because of this DOD specifies some limitations on the system which may be contrary to theory (26:encl 2 pp 3-5). They include:

1. A Procurement cycle minimum of three months and maximum of three years will be used. Exceptions to these limits are permitted with justification and DOD approval.

2. The safety level will not exceed 3 standard deviations of lead-time demand or more than the mean lead-time demand which ever is less.

3. A negative safety level may be replaced by zero.

4. Items may be grouped for determination of levels of support.

5. One time requirements shall not be included in determining EOQ but should be added to the EOQ after it is determined.

6. Provisions for incremental deliveries, price breaks, and related topics should be included in systems.

The Air Force System

The procedures used by AFLC to manage EOQ items are contained in AFLCR 57-6. The five Air Logistic Centers (ALCs) carry out AFLC's responsibility for managing these items. Each EOQ item is assigned to only one ALC. Item requirements computations occur four times a month (once a month for low annual dollar demand items). The EOQ system determines the total EOQ by summing the EOQ based on demands and the quantitative requirement, where the quantitative re-

quirement reflects one time demands such as for war reserve material (WRM), initial stock, or foreign military sales. Since 31 December 1983, the EOQ based on demands has been calculated for each item (5). Previously, tables, one for each ALC, were used to determine the EOQ based on demand for each expected dollar value of annual demand. The tables contained the appropriate EOQ to buy expressed in years of supply. Tables were used because the original computer used by the system could not efficiently perform all the calculations required. The demand used to determine the EOQ is obtained by multiplying the average demand over the past eight quarters by a forecast of the future activity of the system which contains the item. If the item comes from an F-15 and the F-15 flying hour program is expected to double, then the expected demand would be doubled.

The reorder point is determined by adding lead-time requirements, dueouts, safety level requirements, and quantitative requirements. To determine the lead-time demand requirements AFLC multiplies the demand rate, based on eight quarters history, by the sum of the administrative and production lead-times experienced on the last buy of the item. A formula developed by Presutti and Trepp (22) determines the safety level. The safety level formula includes holding cost, EOQ, unit cost, an implied shortage factor, average requisition size and standard deviation of lead-time demand. AFLC headquarters develops the implied

shortage factor to manage overall system performance. Eight quarters of history serve as the basis for the requisition size. The standard deviation of lead-time demand is based on the lead-time required for the last purchase of the item and on the mean absolute deviation (MAD) of demand, the difference between the actual quarterly demand and the average demand over the past eight quarters. The remaining factors are the same as those used for determination of the EOQ.

The Model, DOD Requirements, and the Air Force System

The model assumes that the system contains a single echelon, and a single source. The Air Force manages EOQ items at five Air Logistics Centers (ALC), but manages each item at only one ALC. AFLC treats the ALC's independently. "Individual EOQ tables . . . are needed since ordering and holding costs vary by ALC" (7:p.7-4). The Air Force has five single echelon, single source systems.

The model assumes order placement occurs immediately upon reaching the reorder level. The Air Force computes requirements for most EOQ items four times a month (7:p.1-1). They compute requirements for the remaining items only once a month, but add a factor to compensate for the lag-time (7:p.7-3). Considering the minimum procurement cycle of three months specified by DOD and the six month minimum cycle used by the Air Force and considering the variability of demand and lead-time, four times a month is close enough to "immediately."

The assumption of known, constant, unchanging demand does not reflect reality. Models have been designed which permit probabilistic demand. The 1970 study by Presutti and Trepp (22) produced a formula for the EOQ in addition to the formula for the safety level. Coile and Dickens state:

> However, variability in demand was not considered important enough to use in the order quantity formula recommended in Presutti and Trepp's Model IV. Instead, the Wilson lot size formula is used [9:57].

Although the formula does not include the variability of demand, demand is a factor. Chapter 5 of Coile and Dickens reviews the research performed to develop forecasts of the demand process for use in Air Force EOQ models. Little research had been performed. None of the studies reviewed provided a better method of forecasting demand than the two year moving average that AFLC uses. Later, Smith evaluated a method of determining C-141 EOQ item requirements based on the forecast flying hour program rather than on past demand. He concluded that a flying hour based forecast was "over eight percent more cost effective" (24:26). In the description of his methodology, he stated he had difficulty finding a test sample because the system could not relate demands for an item to a given base or aircraft series (24:11). An Air Force Academy study of the EOQ system also investigated demand. The study recommended "Use single exponential smoothing (with tracking signal to shift

between high and low smoothing controls), for predicting demand . . ." (8:59). AFLC currently develops demand factors using a two year moving average and modifies this demand factor by a forecast of future system activity when the item can be related to a system (7:p.7-2).

For the safety level determination the assumption of a probabilistic demand with an exponential distribution used to approximate a normal distribution replaces the constant demand portion of the assumption (22:2). A 1982 study by Demmy found:

> that the distribution of actual quantity demand about the forecasted value is a highly skewed distribution with significant levels of probability in the right-hand tail of the distribution [10:9].

The study developed several models for lead-time demand and, using a simulation technique, evaluated them against one another and current procedures. The model using an exponential demand pattern and constant lead-time provided the best combination of accuracy and computational practicality. The study concluded that with small changes in the current formula and without an increase in data requirements "significant improvements in inventory management effectiveness may be achieved . . ." (10:28).

The constant lead-time assumption does not reflect the real world. Intuitively, it appears unreasonable to assume the amount of time it took to prepare a purchase request, process the request through procurement, provide the items and place them in stock the last time a buy occurred will be

exactly the same the next time a buy occurs. In his 1982 study Demmy included an evaluation of lead-time variability as well as demand variability in his efforts to determine lead-time demand. He found:

> Lead-time variability has major impacts upon requirements for safety stocks. However, accurate data describing lead-time variability is extremely difficult to obtain from current AF data systems. Additional work to improve capabilities for lead-time forecasting is greatly needed [10:2].

The objective in the assumption has been expanded from minimizing total cost only to one which includes a "constraint on time-weighted, essentiality-weighted requisitions short" (26:2). The Air Force determines the EOQ without considering the DOD constraints. The safety level formula compensates for the DOD constraints (7:7-3). The formula contains an implied shortage factor which can be developed to account for item essentiality, backorder costs, total backorder limitations or similar constraints. A simulation study by Hawks produced several tables (17:Tables 9-14) showing the effect of various holding, implied shortage cost combinations on buy dollars, backorders and fill rates. The tables "can be used to determine which shortage cost to use to maintain spending within current years budget" (17:2).

The cost assumptions do not strictly reflect the real world. Coile and Dickens state:

> Unfortunately, the assumptions of the basic Wilson model . . . do not apply to real world situations and the determination of the unit cost, order cost and holding cost factors are frequently constrained [9:78].

Hadley and Whitin state that a constant unit price times the quantity ordered is a "satisfactory approximation," but that "it will not be correct if quantity discounts are available . . ." (15:11). Coile and Dickens noted that the Air Force was losing money because it was not taking advantage of quantity discounts (9:30). A later study by personnel from the Air Force Academy developed a method which could be used by AFLC to obtain price discounts and recommended its adoption (8:30-44). Current AFLC EOQ procedures include the Air Force Academy recommendations (7:Ch.12).

According to Hadley and Whitin, the Wilson EOQ model is based on the assumption that the cost of placing several orders is equal to the cost of placing one order times the number of orders (15:13) and that the holding cost is "the fraction of the average investment in inventory for a year which is incurred as carrying charges for the year" (15:13). As pointed out by Coile and Dickens "The Air Force EOQ models . . . need accurate and well defined cost factor inputs if an optimum quantity of material is to be procured" (9:78). They also noted that DODI 4041.39 provided procedures to develop the cost to order and the cost to hold, but that good figures did not then exist (9:82-90). In 1975 Farmer and Young completed a study which developed cost to order factors for each ALC which "shows on an element-by-element basis the development of the variable cost-to-order and how this cost can be updated periodically" (13:ii). The

ordering costs are updated periodically to reflect changes in civilian pay rates, but have not been updated to reflect changes in the work required based on changing procedures. A study to update the standards was in progress in July 1984 (18). DODI 4041.39 provides specific guidance to be used to develop holding cost factors (26:encl 4 p 3). Within AFLC, the holding costs are updated annually (17:1). The effects of various levels of holding costs are considered in a study by Hawks (17). The study resulted in charts showing the relationship between holding costs, shortage cost, and buy dollars (or backorders or fill rates).

The Air Force recognizes that the assumption about delivery of the entire quantity at one time is not strictly true. It accepts the assumption and defines, for the purpose of EOQ computation, delivery as "at least ten percent of the total contract or purchase order quantity" (7:p.1-1).

The Air Force system complies with DOD guidance. As shown earlier the system is designed to meet the DOD objective. The Air Force uses the DOD maximum procurement cycle of three years but uses, with DOD approval, a minimum procurement cycle of six months, twice the DOD specified minimum. The Air Force constrains safety levels to match the DOD minimum of zero and a maximum of the lesser of the mean lead-time demand or three standard deviations of the lead-time demand. The Air Force follows DOD requirements by grouping items to determine level of management attention

and by adding one time requirements to demand based requirements. In addition to following the specific guidance, the Air Force makes use of the DOD recommendation to incorporate features in the system to make it better. As an example, the Air Force includes a forecast of future activity in its demand forecast and has provisions for taking advantage of quantity discounts.

The Implied Assumption

Up to this point the mathematical models and assumptions necessary to develop a best policy for determining how much to order and when to order have been reviewed. The optimal solutions to the mathematical model should result in "good" operating doctrine in the real world (15:25). One obvious assumption has been implied throughout. The assumption is that the system used will follow the optimal doctrine. This assumption means the optimal quantity will be ordered at the optimal reorder point. The AFAA report invalidated this assumption. Funding shortfalls forced AFLC to buy less than optimal quantities (1:7). Procurement personnel shortfalls caused AFLC to adopt a six month minimum buy policy (1:5). AFLC buys larger than optimal quantities at other than optimal reorder points.

Since the review focused on the minimum buy policy, particular attention was paid to comments related to minimum buy constraints and order frequency. DOD recognized the need for some constraints to keep the EOQ systems workable

and specified a minimum three month and maximum three year procurement cycle (26:encl 2 pp 3-5). They also permitted adjustment of procurement cycles, with DOD approval, when necessary as a result of funding or personnel limitations. DOD approved the AFLC six month buy limitation (1:5). As part of its study the Air Force Academy compared simulations of the Air Force EOQ system with and without the DOD procurement cycle constraints (8:App.B). Eliminating the minimum and maximum procurement cycle constraints produced no change in acquisition cost, a decrease in holding cost, a decrease in ordering cost, a decrease in total cost, but an increase in procurement actions. The Hawks study contained a table showing the increase in orders as the holding cost increased (17:Table 1) but reached no conclusions. Coile and Dickens questioned the assumption that cost to order is constant. They indicated that perhaps this assumption "could be replaced more realistically by an increasing cost per order" (9:85). Later in the same paragraph, they state, "Obviously, there is a limit to the number of orders that can be handled, but that limit has not yet been reached" (9:85).

From the AFAA audit and the AFA study it appears that establishing a six month minimum buy policy detracts from the optimal solution. This leads to the question: Is it in the best interest of the USAF to arbitrarily increase the minimum procurement cycle period from three months to six

months or twelve months considering the uncertainty in demand forecasting, lead-time forecasting and cost factor estimating, which provide the basis for the calculated procurement cycle period?

III. Research Methodology

Overview

The first investigative question, the one concerning the effect of changing the minimum PCP, is investigated using two models, a simplistic model and a simulation model. Each model is run using actual AFLC item data for alternative minimum PCP policies. The performance measures observed are compared and the effect of the various policies determined. The second question, the one concerning inaccurate cost estimates, is addressed using a mathematical derivation.

This research addresses questions which relate specifically to AFLC. The research models reflect AFLC policies, methods, items, item data, and parameters. AFLC policy and methods are obtained from AFLCR 57-6, Requirements Procedures For Economic Order Quantity (EOQ) Items, (7) and from the regulation OPR (20). The computer system prescribed by the regulation is known as the D062 system. The items and item data used in this research are obtained from quarterly extracts from the system maintained on tape for use on the Computational Resources for Engineering and Simulation, Training and Education (CREATE) time-sharing computer system. The parameters used by the D062 system, holding cost, ordering cost, and implied shortage factor, were obtained from the AFLC OPR (20) for the appropriate period.

Theory

The classic model of an EOQ inventory system discussed in Section II is based on restrictive assumptions including constant demand, constant lead-time, and constant costs. Given an inventory holding cost, an ordering cost, a unit cost and a demand rate, the Wilson EOQ formula, Eq (1), produces a quantity Q to buy which will minimize the ordering and inventory holding costs. Once Q has been calculated, and assuming a constant lead-time, the reorder level and cycle time or PCP can be calculated. Given no change in costs, demand or lead-time the system will operate at minimum total cost if orders for Q quantity are placed at intervals equal to the PCP.

Most people in positions to set EOQ system policy understand classic EOQ theory. Classic EOQ theory, however, addresses problems and minimizes costs that seem less real than the everyday problems the policy maker faces. The problems that are real to the policy makers are obtaining funds to make purchases, processing requisitions, and answering for backorders. The policy maker does not have to budget for the costs minimized by EOQ theory, holding, ordering, or backorder costs, and, therefore, is not concerned with them. The policy maker is concerned with reducing the paperwork that must be processed and the number of buys that have to be processed. The policy maker is also concerned with improving support by increasing inventories.

The manager would like to make these improvements but definitely does not want to increase the amount of money that must be obtained.

A frequently proposed solution to the practical problems is to increase the quantity ordered at one time, to increase the EOQ. The apparent advantages of this proposal are appealing. Buying in larger quantities will reduce the number of buys required, reducing paperwork and manpower requirements. The increased quantity purchased will increase the inventory, improving support. Since the same amount is being purchased, just more at one time, the proposal should not require more money. The price for these advantages is an increase in holding cost for the additional inventory. To an EOQ system policy maker, the increase in holding cost is insignificant because funds do not have to be obtained to pay for the increased holding cost. Increasing the quantity purchased at one time, or if the quantity is expressed as months of supply to buy increasing the PCP, appears to be desirable but, is it really? When this solution is applied to many items over a period of time will the proposed benefits really accrue? The models are used to evaluate this concept and to determine if proposals to increase the PCP are as good as expected.

The Simplistic Model

Purpose. The simplistic model provides for a comparison of policies using AFLC procedures and parameters, but

under ideal and, therefore, partially unrealistic conditions. The ideal conditions reduce the number of factors that may confound the results permitting a better evaluation of the theory. This permits a simpler model which in turn permits the model to use all the D062 items as input data. This is a big advantage over a probabilistic simulation model which must use a very small sample. The unrealistic conditions mean that the absolute values of the results are not directly applicable to AFLC. However, the comparative results permit evaluation of the theory and indicate the relative affects of the various policies.

The Model. The simplistic model is written in FORTRAN to be run on AFLC's CREATE system for this research. The FORTRAN code which makes up the model is included as Appendix A. The following paragraph describes the process the code implements.

The simplistic model is based on deterministic demand and deterministic lead-time. These assumptions permit the calculation of a fixed EOQ and a fixed cycle time for each item. Since these factors are fixed, the quantity and date of future purchases can be calculated. The model begins by reading data for an item and from the data determining the EOQ, cycle time, and reorder level. Using the reorder level and inventory information from the tape, an initial buy date or quantity short is determined. If the inventory is less than the reorder level a "buy" is made for the shortage

quantity plus an EOQ, and the buy date is established one cycle time into the future. A "buy" is made by accumulating the dollar value of the buy into the appropriate element of one array and by incrementing the appropriate element of the large or small buysize arrays. There are elements in each array for each year, policy combination. After the initial buy date is established, all the remaining dates in the ten year period of the model are established by adding the cycle time to the last buy date. As each buy date is established, a "buy" as described above is made. The determination of the EOQ, calculation of the reorder level and ten year cycle, is then repeated for each of the minmum PCP policies. The entire process is then repeated for all of the items in the data base which have a demand history. Items without a demand history are excluded, because without a demand history the EOQ and cycle time cannot be calculated.

Procedures. The model described above is run using actual D062 data as input. Since the data are stored on separate tapes for each ALC and since each ALC has different cost parameters, the model is run once for each ALC, and the results summed to determine an AFLC total. The tapes used are from the quarter ending 31 December 1983. These tapes were chosen because they were the most recent available, and reflected the most current items and policies. One policy which had recently changed and was reflected in these tapes was the method of determining the EOQ. The latest proce-

dures calculate the EOQ exactly. Previously, an approximate EOQ was obtained from a table stored in the computer. This change made it easier to duplicate AFLC's procedures in the model and rectified a shortcoming of the system which had been identified in the AFAA study (1:iv).

The Simulation Model

Purpose. The simulation model permits the evaluation of alternate minimum PCPs under more realistic conditions. The realistic conditions may mask some of the effects of the theory described above, but they provide a better estimate of the affect of changing the minimum PCP under real world conditions. The simulation model permits the evaluation of more performance variables and permits inferences about the magnitude of the changes. The assumptions necessary for the simplistic model preclude backorders and excesses. The ideal system provides perfect support. The only performance indicators obtained from the simplistic model are the dollars spent and the number of buys. The simulation model permits real world occurrences such as backorders and excesses, and includes them as performance variables to be measured. The more complicated model requires more time to run and thus does not permit the use of the entire population. A sample is extracted and run, which is a disadvantage of this model compared to the deterministic model. The results are then extrapolated to the whole population.

__The Model.__ EOQSIM is the simulation model used by AFLC/MMMAA to evaluate policies and parameters proposed for inclusion in the D062 system and the one chosen for this work. It is a FORTRAN based model which has evolved from the Inventory System Simulator, INSSIM, described and well documented by Demmy in two reports (11,12). Unlike its ancestor, EOQSIM is not well documented. Documentation is limited to comments in the code and personal notes maintained by users of the model. The description of the system below is based on a review of the code and information provided by the chief of the requirements analysis section (14).

Model input requirements are data on items extracted from the D062 system, a flying program forecast, and a set of run parameters. The data from the D062 system provide the model with item identification data, demand history and requisition size information. The model uses the demand and requisition history to develop a distribution which the model will sample to obtain future requisitions. The flying program forecast consists of eight quarters of history and twelve quarters of programmed activity for selected weapon systems. The flying program information is used much as it is in the real system to modify future requirements forecasts to compensate for planned increases or decreases in activity. The run parameter cards permit the system user to specify the type of output desired, the management method to

be used, the parameters to be used, and run identification information.

The simulation begins by reading the run and management method parameters. The flying program data are then read and flying program factors calculated for later use. The simulation of each item is begun as the data for each item is read from the data tape. The demand pattern for the item is established, and the demands for future quarters are calculated using a Monte Carlo technique based on the historical mean absolute deviation, the flying program factor and a 0,1 random number stream. The calculated demands are stored in an array for future use by the simulation routine. The simulation of activity for the first replication for the first implied shortage cost is then begun. Each replication of each run is begun by placing the items in its steady state condition for the current AFLC policy. Data from the tapes are used to establish the initial values for inventory, backorders, due-ins, etc. that will be used for each pass through the simulation. The simulation is centered on a list of events which is used to keep track of the time when various activities or events will occur. The events which can occur include housekeeping events such as recording statistics at the end of each quarter, and events which represent real world occurrences such as requisitions, returns, level computations, orders, and deliveries. As each real world type event becomes due, it is processed in

much the same manner as it would be in AFLC. Alternative procedures for some of the events are built into the simulation and must be specified on the run parameter cards. For example, there are several alternative methods for calculating the EOQ and safety level included in the simulation. Each time a real world type event is performed, the appropriate statistics are accumulated. At the end of each quarter the statistics are written to a permanent array and the statistical counters are reinitialized for the next quarter. This process is repeated until the end of the simulated time. If the simulation is to be run with more than one implied shortage factor the model is reinitialized and the simulated clock is reset to zero. The model is then again set in motion using the same demand pattern, but storing the output in a different array. Once all the shortage factor runs have been made, a new set of demands is calculated if there are to be multiple replications of the simulation. The shortage factor runs are then repeated with the new demand pattern. After all the replications have been made for all the shortage factors, data for the next item are obtained and the process is repeated. After all the items have been processed, selected statistics are printed out for analysis.

For the purposes of this research EOQSIM had two shortcomings both related to the output statistics. The model, in its current form, was used primarily to evaluate

the effect of alternative shortage cost parameters. The output was designed for this purpose. The output provides replication averages for a number of performance measures for each shortage cost. The first shortcoming was that the performance measures output did not include information on large and small buys even though the information was generated in the simulation. The second was that individual replication results would be required for statistical analysis of the results. The first shortcoming was resolved by modifying the program to include the buy size statistics in the output list. The second problem was resolved by replacing the run number parameter in the output array with the replication number. This limited the number of shortage factor runs to one, but for this research only one is required. This solution created another problem. The output format limited the number of replications to ten. Since more than ten would be required, a method had to be developed to keep from repeating the same ten replications each time the simulation was run. The solution was to include a random number seed in the input parameters which replaced the fixed seed written into the program. Replications then can be run in groups of ten if different random number seeds are included in the input parameters.

Procedures. The EOQSIM model is run using the same D062 data tapes used by the simplistic model. The flying program data file is developed from historical data (3) and

programmed data (2) with an as of date of 31 December 1983 to coincide with the D062 data. The run parameter cards specify the current AFLC procedures and methods of calculating the EOQ and reorder level. Separate runs are made to reflect three, six and twelve month constraints on the minimum PCP. The random lead-time and random requisition size options are selected, but the funds constraint option is not used.

The simulation model requires much more computer run time than the simplistic model and, since it is a simulation model, several replications are made to permit meaningful conclusions. Because of this the simulation model is run using only a sample of the items from each ALC. The samples used consist of ten percent of the items which have a demand history. A demand history is necessary since the model uses this history to determine future requirements. The items are extracted from the total item files by the program used by AFLC to extract their samples. A sample size of ten percent was chosen as a compromise between a desire to use all the items and the computer time required to run larger sample sizes.

Using a sample creates a problem in combining the results to obtain an AFLC position. Since the simplistic model used all the items from each ALC the individual ALC totals could be summed. With simulation, the sample results are extended to form the ALC total, and then, the ALC totals

summed to form an AFLC total. This procedure is reasonable only if each ALC sample is representative of the entire ALC population. To ensure the sample is representative the number of items with selected characteristics in both the population and the sample are determined. The number in each category is compared using a Chi square test to determine if the sample is a reasonable representation of the population. The characteristics and categories used are those that AFLC uses when they extract a small stratified sample. The characteristics and categories are listed below. The characteristics and categories are self explanatory except for the weapon system categories, which are codes that represent aircraft. As an example, 101Z is the code for the B-52 aircraft.

CHARACTERISTIC	CATEGORIES
Weapon System	101Z, 410A, 400Z, 119Z, 476Z, 411Z, 129Z, 107C, 133Z, 482Z, 337Z, 329Z, 327Z, 420Z, 328Z, 320Z, 324Z, 443Z, 485Z, 380E, 9999, X&T, OTHER
Annual Demand	1-5, 6-10, 11-20, 21-50, 51-200, 201 and up
Annual Dollar Demand	$1-$300, $301-2000, $2001-5000, $5001-10,000, $10,001-20,000, $20,001 and up
Unit Cost	$0.10-20.00, $20.01-50.00, $50.01-150.00, $150.01-300.00, $300.01-500.00, $500.01 and up
Total Lead-time Months	1-6, 7-8, 9, 10-11, 12-14, 15 and up

Once the samples are obtained and verified, the model is run for each sample for each of three policies, three

month minimum PCP, six month minimum, and 12 months minimum. Three runs of ten replications each are made for each ALC sample, policy combination, for a total of thirty replications of each combination. Thirty replications was chosen as a compromise between precision and the computer run time required. Thirty replications permit the estimation of output variables with an accuracy of plus or minus 0.36 standard deviations at a 95 percent confidence level, assuming the central limit theorem applies, and using a formula developed in a text by Shannon (23:187-190). The model produces a number of performance statistics for each of three years, the current year, the apportionment year, and the budget year. Of the statistics that the model produces the ones that are applicable to this work and those that will be later analyzed are dollar value of year end inventory, dollar value of item in long supply (inventory greater than the EOQ plus the reorder level plus two years supply), dollar value of the safety level, number of requisitions on backorder, number of units on backorder, dollar value of the safety level, dollar value of the buys made during the year, and the number of large buys made. From the statistics generated by the model the total system cost (ordering cost plus holding cost plus backorder cost) will be calculated. Once all the runs are complete, the AFLC totals will be calculated. The total for each performance statistic is compared to determine if there is a

difference in performance based on policy and year. The ANOVA procedures contained in the Statistical Package for the Social Sciences (SPSS) are used to perform this test. If the F test indicates a difference, the SPSS Duncan range test is used to determine which policies produce results that are different at the 0.05 level of significance.

IV. Results

Overview

During the performance of the simulations, problems occurred which required modifications to the original plans. Three problems were encountered with the D062 extract data files. Some of the data elements used by the simplistic simulation contained numbers overprinted with plus or minus signs. This is a carryover from earlier days when storage space in computers was more limited. To rectify this situation a routine was written and included in the simulation to translate the overprinted characters into useable numbers. The second problem occurred because the files were generated using COBOL and read using FORTRAN. For some variables FORTRAN could not properly provide the implied decimal point. This problem was resolved by reading these variables as whole numbers and having the program provide the proper scaling factor. The third problem appeared to be more serious. The data tapes purported to be from the Oklahoma City Air Logistics Center produced WR when the ALC code was printed rather than the expected value of OC. After consultation with the person responsible for the data tapes (19), it was concluded that a problem did not exist. A check of the number of the records in the file and a detailed check of a record confirmed that the tapes actually contained data from Oklahoma City ALC. The data

tapes available for use on CREATE are not the original D062 system tapes. They are copies of the tapes. On the original tapes the ALC code is a one digit entry in the middle of a long data record. For the convenience of the users a two digit alpha ALC code is added as the first two characters in each record when the CREATE tapes are generated. In this case the program was not changed to reflect the proper ALC when the source tapes were changed from Warner Robbins to Oklahoma City.

Another problem occurred when running the simulation model. There were some combinations of random numbers and item characteristics that caused the model to abort. After consultation with the Chief of the Requirements Analysis Branch (14), it was determined that the only solution was to delete the items causing the problems from the sample. The result was that all the combinations of policy and replication were not run with identical samples. The difference between the original and final samples ranged from a maximum 19 (5419 to 5400 for San Antonio ALC) to minimum of 0 (2433 for Sacramento ALC). Chi square tests were run on the final samples, and in all cases on all measures the sample Chi square values were less than the critical Chi square value at the 95% confidence level. Given these two facts, the simulation results are not considered to be any less valid than they would have been had the items not been de ted.

The Simplistic Model

The simplistic model was run once for each ALC using data from the quarter ending 31 December 1983. The output from the five runs were then summed to obtain AFLC totals. It is these totals that were analyzed and are discussed in the following paragraphs.

The population statistics collected along with the performance statistics show that 229,677 items were processed by the model. Of that total 42,319, 18 percent, had PCP's of less than one year and were affected by at least one PCP policy. Those affected by the policies accounted for approximately 94 percent of the dollars spent, based on the ten year total dollars expended, averaged over the four policies. They account for virtually all the large buys under any of the policies and for 35 percent of the small buys for the one year policy, 49 percent for the 6 month policy and 54 percent for the other two policies. The items affected by the minimum PCP policies made up only a small portion of the total population but were responsible for most of the significant actions, dollars spent and number of large buys.

The results relating to the number of buys are summarized in Figure 1. The values used to create the charts in Figure 1 are contained in Appendix B. The charts indicate that the number of buys for each policy follow a similar pattern. The number of buys increase sharply

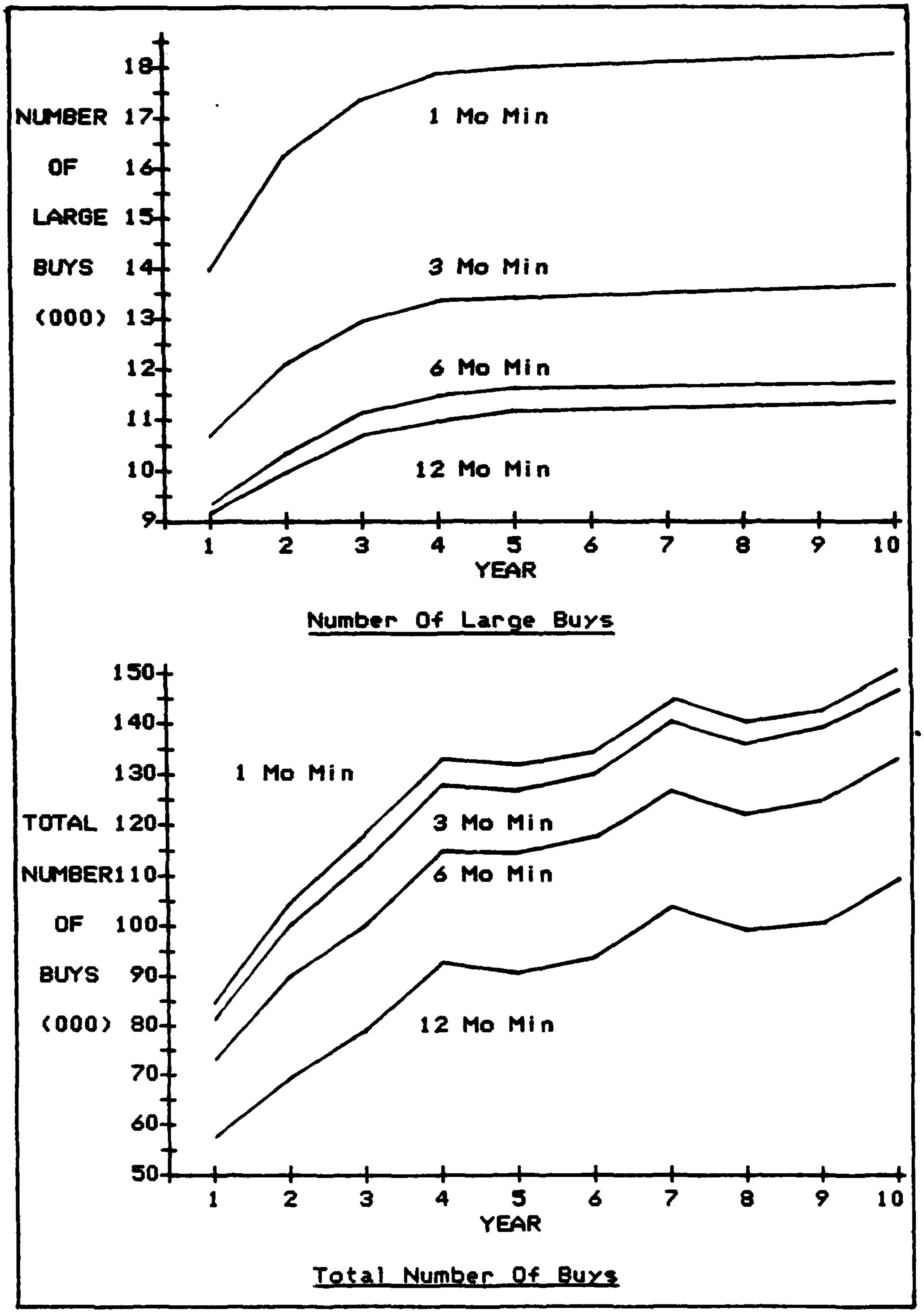

Fig. 1. Number of Buy Results for Simplistic Model

through the first four years. Over the remaining six years the general trend is for the number of buys to stabilize, although there is variation from the overall trend in individual years. The number of large buys for all years decrease as the minimum PCP is increased from one to three to six months to twelve months. The chart depicting the total number of buys shows that the number of buys decrease as the minimum PCP increases. The amount of the decrease between successive minimum PCPs becomes larger as the minimum PCP increases. These results tend to support the solution proposed in Section III. Increasing the PCP decreases the number of buys required.

The results for the number of dollars spent do not support the idea that increasing the PCP does require additional funds. The results are summarized in Table 1. The table lists the total dollars expended for each policy for each year. In addition the absolute and percent differences from the current six month policy are included to show the differences between policies. The absolute differences between the policies in each of the first five years has been highlighted. The increase in the dollars required as the minimum PCP increased was not forecast in the discussion in Section III. There was something wrong with the logic. The logic assumed that one large or two small buys would be made in the same year. This is not necessarily the case. The item characteristics could

TABLE I

Summary of Buy Dollar Results for Simplistic Model

YR	MEASURE	POLICY			
		1 Mo Min ($M)	3 Mo Min ($M)	6 Mo Min ($M)	1 Yr Min ($M)
1	Total Expended	3376.78	3359.22	3370.04	3462.23
	Dif From 6 Mo	6.74	-10.82	0.00	92.19
	Percent Dif	0.200	-0.321	0.000	2.736
2	Total Expended	1509.39	1513.85	1527.87	1562.41
	Dif From 6 Mo	-18.47	-14.01	0.00	34.54
	Percent Dif	-1.209	-0.917	0.000	2.260
3	Total Expended	1637.67	1637.69	1639.14	1650.18
	Dif From 6 Mo	-1.48	-1.45	0.00	11.04
	Percent Dif	-0.090	-0.088	0.000	0.674
4	Total Expended	1692.39	1694.13	1697.04	1700.98
	Dif From 6 Mo	-4.65	-2.91	0.00	3.94
	Percent Dif	-0.274	-0.171	0.000	0.232
5	Total Expended	1713.10	1714.47	1714.77	1717.29
	Dif From 6 Mo	-1.67	-0.30	0.00	2.52
	Percent Dif	-0.097	-0.017	0.000	0.147
6	Total Expended	1728.54	1729.24	1730.95	1732.03
	Dif From 6 Mo	-2.41	-1.71	0.00	1.08
	Percent Dif	-0.139	-0.098	0.000	0.062
7	Total Expended	1745.62	1746.17	1746.24	1746.89
	Dif From 6 Mo	0.62	0.07	0.00	0.65
	Percent Dif	-0.035	-0.003	0.000	0.037
8	Total Expended	1747.82	1749.23	1748.47	1749.59
	Dif From 6 Mo	-0.65	0.76	0.00	1.12
	Percent Dif	-0.037	0.043	0.000	0.064
9	Total Expended	1755.07	1754.29	1754.97	1755.65
	Dif From 6 Mo	0.10	-0.68	0.00	0.68
	Percent Dif	0.005	-0.038	0.000	0.038
10	Total Expended	1759.05	1759.96	1760.05	1760.83
	Dif From 6 Mo	-1.00	-0.09	0.00	0.78
	Percent Dif	-0.056	-0.005	0.000	0.044

require three small purchases in a year. If the policy of ordering twice the EOQ were adopted, two large buys would be made in the first year. One would be made when the first small buy was made and the second when the third small buy would have been made. Three EOQs would be bought during the year if the actual EOQ results were used and four EOQs, two buys of twice the EOQ, would be bought using the increased PCP policy. In the long run the amount purchased under each policy would be the same, but under an increased PCP policy more is required in the early years.

In years five through ten the differences between policies become smaller and any trends become less identifiable. This reflects the situation envisioned in the discussion in Section III. It indicates that approximately five years are required for a policy change to become fully effective. It takes five years for the majority of the items to be bought up to, or used down to their new policy average inventory levels.

Another trend observable from the data is the difference between years rather then between policies. In the first year a large buy is made as initial shortages are purchased. In year two there is a sharp drop in the number of dollars required because of the large initial purchases. From years two through seven there are large but decreasing increases in the dollars required each year. This reflects the use of the large initial buys and the entry of items

originally in an excess position into the buy cycle. After year seven the increases continue, but are relatively small indicating that the constant demand and constant lead-time conditions have damped the chaotic initial conditions created when the system was operated in the real world.

From both the number of buys and the value of the buy information generated by the simplistic model conclusions several conclusions can be drawn. Increasing the PCP decreases the number of buys required. Increasing the PCP from one to three to six months affects primarily large buys, while increasing from six to twelve primarily affects small buys. Increasing the PCP requires additional funds during the transition period with larger PCPs requiring disproportionately larger amount of money. The last conclusion is that the transition period, the time it takes for the new policy to impact all of the items, is approximately five years.

The Simulation Model

The simulation model was run three times for each of the minimum PCP policies, three months, six months, and one year, for each ALC. Each run produced ten replications and generated output statistics for several performance measures for each of the years. The sample data values for each ALC were extrapolated to represent the ALC totals by multiplying by a factor obtained by dividing the ALC total number of items by the number in the sample. The system operating

cost was calculated at this point to provide another performance measure. The operating cost was calculated by multiplying the inventory by the inventory holding cost, the number of requisitions backordered by the implied shortage cost, the number of large buys by the large order cost and the number of small buys by the small order cost. The AFLC totals for each performance measure, year, policy, and replication were then determined by summing the ALC values. The AFLC values were subjected to analysis by the Statistical Package for the Social Studies. A one way ANOVA with a Duncan ranges test was performed for each variable.

The results of these analyses were summarized and are contained in Table 2. Within each performance measure the average value of the AFLC totals over thirty replications is provided for each of the nine policy year combinations. In many cases there is no statistically significant difference between values at the 0.05 level of significance. These values are indicated by a superscript. For example, within the performance measure "Total Number Of Buys," the number of buys in year one for the six month policy, 54,480 is not significantly different from the number of buys in year two for the six month policy, 54,901. The number of buys in year two for the six month policy is different from the number of buys in year two for the twelve month policy, 46,169, but the values for years two and three for the twelve month policy, 46,160 and 46,560 are not significantly

TABLE II

Summary of Results for Simulation Model

PERFORMANCE MEASURE	MIN PCP	YEAR 1	YEAR 2	YEAR 3
Ending Inventory ($M)	3 Mo	2902[1]	2909[1]	2899[1]
	6 Mo	2865[1]	2996	3050
	1 Yr	2913[1]	3186	3297
Total Number Of Buys	3 Mo	57,186	59,779	61,484
	6 Mo	54,480[2]	54,901[2]	56,198
	1 Yr	49,890	46,169[1]	46,560[1]
Number Of Large Buys	3 Mo	7523	7259[2,3]	7328[3]
	6 Mo	8007	7129[1,2]	7037[1]
	1 Yr	8946	7003[1]	6722
Dollar Value Of Purchases ($M)	3 Mo	1211	1019[1]	1011[1]
	6 Mo	1311	1059[2]	995[1]
	1 Yr	1560	1077[2]	1004[1]
Requisitions Backordered	3 Mo	48,594[2]	41,244[1]	41,296[1]
	6 Mo	49,557[2]	41,609	40,954[1]
	1 Yr	57,827	46,533	41,332[1]
Units Backordered	3 Mo	408,100[2]	316,300[1]	301,300[1]
	6 Mo	406,400[2]	323,800[1]	290,100[1]
	1 Yr	533,800	426,400	304,900[1]
Value Of Safety Level ($M)	3 Mo	235.8	261.6	269.9
	6 Mo	213.1	239.2	245.5
	1 Yr	165.5	188.1	194.9
Long Supply > EOQ+ROL+2Yr ($M)	3 Mo	1058[1]	1220[2]	1306[3]
	6 Mo	1070[1]	1224[2]	1321[3]
	1 Yr	1073[1]	1249[2]	1355
Holding+Order+ Backorder Cost ($M)	3 Mo	550.7[1,2]	548.8[1,2]	547.0[1]
	6 Mo	544.0[1]	561.6[2]	570.0
	1 Yr	555.5[2]	592.9	608.4

[1,2,3] Within a performance measure indicates that values are not significantly different from other values with the same superscript at the 0.05 level of significance. Superscripts are omitted if they do not affect comparisons between policies or across years.

different. To minimize confusion, insignificant differences which do not affect comparisons between years or between policies are omitted.

These results, like the results for the simplistic solution, indicate that the benefits of the proposed solution discussed in Section III will not all occur. Ignoring holding costs and increasing the PCP is not as appealing as it initially appeared. The reduction in the number of buys that should have resulted from increasing the PCP did occur. In the first year, however, the number of large buys increased significantly. This is caused by some items being initially at an inventory position below the reorder level, plus the fact the buy size is larger due to the increased PCP. In these cases the first buy will be for the EOQ plus a quantity to make up for the initial shortage. If the EOQ is a small buy the addition of the shortage quantity will sometimes cause the total buy to breach the large buy threshold.

The increase in the inventory that should have occurred did occur, at least in the second and third years. The lack of an increase in the first year is understandable when one considers that the time between the identification of the buy requirement and the delivery of the order, the lead-time, typically range from 9 to 24 months. The increased inventory was supposed to have led to better support. This did not occur. The number of requisitions and units on

backorder either increased with increasing PCP or were the same for all policies. This reflects the fact that backorders are not related to total inventory, but instead to the inventory on hand when an order is placed, to the reorder level. A backorder occurs when the demand during the lead-time is greater than the reorder level. Backorders are related to the EOQ in two ways. Increasing the EOQ reduces the number of buys. Reducing the number of buys reduces the exposure to potential backorder conditions, and therefore the number of backorders. Increasing the EOQ, using AFLC's safety level formula, reduces the safety level and therefore reduces the reorder level. The reduced reorder level results in an increased chance of a backorder when a buy is made. The reduced reorder level is the dominant effect in the first two years. More backorders occurred for the higher minimum PCP policies. By the third year the increased EOQs had been delivered and the reduced exposure began to offset the reduced safety level. The difference in the number of backorders between policies became insignificant.

A critical feature of the proposed solution was that it would not cost more to buy in larger quantities at less frequent intervals. The results of the simulation model verify those of the simplistic model. More money is required in the first year for the larger minimum PCP policies. In later years the difference between the amounts

required becomes less significant. The reasoning is the same as that used in the simplistic model. With increased PCPs the same number of dollars is required in the long run, but it must be spent sooner. The additional money spent in the first years is not recovered until the system is closed out.

Investigative Question One

Investigative question one concerned the effect of doubling the minimum procurement cycle period from three months to six months and again to twelve months on a number of performance measures. The answer to the question for each performance measure as indicated by the results of the two models follows:

1. Value of Inventory: At the end of three years the additional value of the on hand inventory was $101 million, or five percent higher, when the six month minimum policy was selected over the three month minimum policy. When the one year minimum was selected the additional value of the inventory was $247 million, or eight percent larger, than the six month policy, $348 million, or 14 percent larger, than the three month minimum policy.

2. Number of procurement actions required: The total number of buys decreased as the minimum PCP was increased. The amount of the decrease varied by year. In the first year there was a decrease of 2706 buys, or five percent, for the six month policy over the three month policy, and a

decrease of 4509 buys, or eight percent, for the one year policy. The corresponding decreases for year two were 4878 buys, eight percent, and 9638 buys, sixteen percent and for year three were 5286 buys, nine percent, and 9638 buys, seventeen percent. The simplistic model indicates that the number of buy differential will continue into the future.

3. Portion of procurement actions requiring high value procedures: The percentage of the total buys requiring high value procedures, large buys, showed a consistent pattern over all years. As the minimum PCP was increased the percentage of large buys increased. In year one, the increase was from thirteen to eighteen percent, in year two from twelve to fifteen percent and in year three from twelve to fourteen percent. If the results are viewed in terms of the number of large buys rather than the percentage of large buys the picture is somewhat different. In the first year the number of large buys increased with an increase in the minimum PCP as does the percentage. The number of large buys in the first year increased from 7523 to 8007 to 8946 as the minimum PCP was increased from three to six to twelve months. In years two and three the results are different. The number of buys decreased as the minimum PCP was increased. In year two the number of large buys decreased from 7259 to 7129 to 7003 as the PCP was increased from three to six to twelve months. (At the 0.05 level of significance the three and six month values were not

significantly different, and the six and twelve month values were not significantly different.) The corresponding values in the third year were 7328, 7037, and 6722.

4. Stock fund dollars committed: Both models showed that increasing the minimum PCP increased the dollars required in the first years but that over time the differences disappear. The simulation model indicated that in the first year an additional $100 million dollars was required when the policy was doubled from three months to six months and that an additional $249 million was required when the minimum PCP was doubled again to twelve months. In the second year the differences were much smaller, $40 million between three and six months and a statistically insignificant $18 million between the six and twelve month policies. In the third year the maximum difference between any of the policies was a statistically insignificant $16 million. The simplistic model indicates the additional initial investment is not recovered, at least not in ten years. This result should be expected. The additional funds went into increasing the average inventory level and will not be recovered until the additional inventory is liquidated. The inventory is likely to be liquidated in one of two ways. A policy change may occur which will require lower inventory levels. In this case the additional investment will be recovered in the form of reduced buy requirements while the inventory is being reduced. The

second reason for liquidating the inventory is because demand has dropped requiring a lower inventory. In this case it is likely that some of the inventory will be declared excess and discarded. In this case the additional initial investment in inventory will be lost.

5. Number of requisitions backordered: The simulation model showed statistically insignificant increases in the number of requisitions backordered in each of the first two years, 963 and 365, as the minimum PCP was increased from three to six months. When the PCP was further increased from six months to twelve months in these years the increase in the number of requisitions backordered was much larger, 8270 and 4924. In the third year the maximum difference between any two policies was a statistically insignificant 378 backordered requisitions. Increasing the amount ordered at one time, and thus the average inventory, does not reduce the number of requisitions backordered.

6. Number of items backordered: The results for the number of items backordered parallel those for the number of requisitions backordered. There were no statistically significant differences in the number of backorders in each of the first two years as the minimum PCP was increased from three to six months. In the first year the six month policy resulted in a decrease from 408,100 backorders to 406,400 backorders while in the second year the result is an increase from 316,300 to 323,800. In both years the twelve

month policy resulted in significantly more backorders, 533,800 and 426,400. In the third year the difference between policies was insignificant. The number of backorders ranged from a minimum of 290,100 for the six month policy to a maximum of 304,900 for the twelve month policy.

7. Value of items in long supply: Long supply, here, is defined as inventory that exceeds the sum of the EOQ, the reorder level, and two years of demand. In each of the first two years there was no statistical difference between different policies. In the first year the maximum difference was $15 million, 1.4 percent, and in the second year $29 million, 2.3 percent. By the third year the difference had increased. The six month policy resulted in a statistically insignificant $15 million increase over the three month policy and the one year policy resulted in a significant increase of $34 million over the six month policy. Buying in larger quantities increases the probability of having more inventory on hand. Then, when demand falls, a long supply or excess situation is created. The trend of the results supports this idea. As the years progress the higher PCP policies accumulate more material in long supply.

8. System operating costs (holding + ordering + backorder costs): The results of the simulation were somewhat surprising. In the first year there was little

difference between the three policies. The six month policy resulted in the lowest cost of $544.0 million, but the three month policy was not statistically different at $550.7 million. The twelve month policy produced the highest cost of $555.5 million, but this too was not statistically different from the three month minimum policy. In the second year the results are more like those expected. The three month policy resulted in the least cost, $548.8 million, but this was not statistically different from the $561.6 million cost of the six month minimum policy. The twelve month policy resulted in the highest cost of $592.9 million. By the third year the costs of each policy were all significantly different. The three month policy cost $547.0 million, the six month policy cost $570.0 million, and the one year policy cost $608.4 million. Upon further consideration the results are not as surprising. The EOQ and reorder level formulas produce results that should minimize the system costs, but they assume inventories, buys, and backorders are the result of the EOQ calculated using the current formula. In this case the inventories and due-ins initially are the result of EOQ calculations performed using the current policy while buys are the result of the new policy. The system operating costs are the result of a combination of the current (six month) policy and the new policy. In year two as the buys made during the first year are delivered and as more items reach their

reorder level for the first time under the new policy the system operating costs reflect more of the new policy and less of the old. The shift will continue into years three and four. Considering the maximum three year PCP and the small number of items with lead-times exceeding two years, the results for year five should virtually represent steady state conditions for the new policy. Considering that over 90 percent of the dollars are attributable to items with PCPs of one year or less and considering the normal lead-times of from 9 to 24 months, the results for year three should be a reasonable approximation of steady state results. The first year results with the six month policy resulting in the lowest cost reflect the fact that the current policy is a six month minimum PCP. The results in year three, increases of $23 million and $38 million, more accurately reflect the theorized results and what should be expected in the future.

9. Percentage of items affected by the minimum PCP policies: Population statistics were gathered as the simplistic model was run. PCPs of one and under were calculated while those greater than one were used as obtained from the data tape. Of the 229,677 items considered, 0.9 percent (2144) had PCPs of 0.25 or less, 5.6 percent (12,909) had PCPs greater than 0.25, but less than or equal to 0.5, and 11.7 percent (26,925) had PCPs greater than 0.50, but less than or equal to one. These items,

comprising approximately eighteen percent of the total, accounted for 94 percent of the dollars spent based on the number of dollars expended over the ten years covered by the simplistic model averaged over the four policies.

Investigative Question Two

The second investigative question was "What change in ordering or holding cost would cause the procurement cycle period to be changed from three months to six months?" This question can be answered by examining the formula used to calculate the PCP.

As given in Section II the formula to calculate the EOQ is:

$$Q = [(2DA)/IC]^{1/2} \tag{1}$$

where Q is the economic order quantity in units, D is the annual demand in units, A is the cost of placing one order, and IC is the holding cost obtained by multiplying a holding cost factor, I, by the unit cost, C.

The PCP is the EOQ expressed in units of time and is calculated by dividing the EOQ by the demand for the time period.

$$PCP = Q/D = [(2DA)/IC]^{1/2} / D \tag{2}$$

Rearrangement produces

$$PCP = (A/I)^{1/2} * (2/CD)^{1/2} \tag{3}$$

For a given unit cost and demand the PCP is proportional to the square root of the ratio of the ordering cost to the holding cost factor. To produce a PCP twice the

original, the ratio of the ordering to holding coat will have to be increased by a factor of four.

The second question was raised because errors in holding and ordering costs were used as part of the rationalization for increasing the minimum PCP. To justify the increase in the PCP the errors would have had to have been quite substantial. Using Oklahoma City as an example the actual large order cost would have had to have been $3066.76 rather than $766.69 assuming the holding cost was correct or the actual holding cost factor would have had to have been 0.04 rather than 0.16 if the ordering cost was correct. Other combinations of errors could have caused the same results if the ratio they form is four times the original ratio of 4792. Errors of this magnitude are possible, but unlikely. Errors in the ordering and holding costs are not good reasons to increase the minimum PCP.

V. Summary, Conclusions and Recommendations

Summary

This research looked at the affect of increasing the minimum PCP from three to six to twelve months on the EOQ items managed by AFLC. Increasing the PCP produced both desirable and undesirable results. Increasing the PCP had the disadvantages of increasing the implied costs, increasing the value of the inventory, and increasing the value of the items in long supply. During the transition between policies, the first year, increasing the PCP had the additional disadvantages of requiring more large buys, requiring more dollars to make purchases, and reducing the support provided. The advantages of increasing the PCP were reducing the total number of buys, and in the long run reducing the number of large buys, and reducing the value of the safety level without increasing the number of backorders. Table three summarizes the magnitude of the changes in the performance measures as the PCP is increased to six or twelve months.

In addition to providing estimates of the values of the various performance measures the research provided some insight into the composition of AFLC's EOQ item data base, and into the dynamics of changing policies. There were 531,691 item records on the D062 tapes. Less than half of the items had programmed monthly demand rates and EOQs

TABLE III

Changes Caused by Increasing the Minimum PCP from Three Months to Six Or Twelve Months

Performance measure	Incr Min PCP To	Change	
		Transition (Year 1)	Long Term (Year 3)
Cost ($M)			
Commit Dollars	6 Mo	+100	-16[1]
	12 Mo	+349	-7[1]
Implied Cost	6 Mo	-6.7[1]	+23.0
	12 Mo	+4.8[1]	+61.4
Support Provided			
Rqns Backordered	6 Mo	+603[1]	-342[1]
	12 Mo	+8873	+36[1]
Units Backordered	6 Mo	-1700[1]	-11,200[1]
	12 Mo	+125,700	+3600[1]
Other Factors			
Total Buys	6 Mo	-2706	-5286
	12 Mo	-7296	-14,924
Large Buys	6 Mo	+484	-291
	12 Mo	+1423	-606
$ Value of Inv ($M)	6 Mo	-37	+151
	12 Mo	+11	+398
$ Value of Safety Level ($M)	6 Mo	-22.7	-24.4
	12 Mo	-70.3	-75.0
$ Value of Long Supply ($M)	6 Mo	-6.7[1]	+23.0
	12 Mo	+4.8[1]	+61.4

[1] Indicates that the difference from the three month policy is not significant at the 0.05 level of significance.

greater than zero, and therefore, less than half were considered by the model. Of the 229,677 items considered by the model 18 percent have PCPs of one year or less and this 18 percent accounts for more than 94 percent of the dollars spent each year. The minimum PCP policies affect the items with the highest annual dollar demand. Substituting high annual dollar demand values in the EOQ formula results in low PCPs. The three month minimum policy affected 0.9 percent of the items, the six month minimum affected 6.5 percent and the one year minimum 18.4 percent.

Changing a minimum PCP policy does not produce immediate results. The impact of the change is felt gradually over a period of time. In the first year the impacts are primarily negative. More dollars are required, the implied costs are higher, the number of backorders is increased, and while the total number of buys is lower, the number of large buys is higher. By the third year the impact of the changed policy is reflected in the performance measures and the long term affects on each can be discerned. There are positive affects and negative affects. Fewer total buys and fewer large buys are required and fewer dollars are tied up in the safety level. More implied costs are generated, more money is tied up in inventory, and the value of the items in long supply has increased. The initial increases in the number of dollars required and in the number of backorders have been reduced and are now the

same across policies. By the fifth year the implementation of a new policy is virtually complete and the results should reflect the long term values. In practice it is difficult, if not impossible, to observe the long term affects of a policy change because the results are affected by so many other system variables that change during the five year transition period. Items enter and leave the inventory, parameters are changed, requirements change, and other policies change (procurement or maintenance for example). These all interact and affect the performance of the EOQ system.

Conclusions

The Air Force Audit Agency report that was the motivation for this research claimed:

> The capability of the Air Force EOQ system to achieve its intended objective was impaired by changes in economic conditions (requirements in excess of funding) and by externally imposed constraints (minimum buy level policy). These factors were the basis for system modifications which resulted in increased holding/ordering costs and average inventory investment costs [1:ii].

The report estimated the increased inventory investment to be $90.6 million (1:iv) and the increased holding, ordering and stockout costs to be $162 million (1:iv). This research only addressed the minimum buy policy, but produced results that tend to confirm the AFAA claims. An increase in minimum PCP from three to six months results in an increase in inventory of $151 million dollars and an increase in

holding, ordering, and stockout costs of $23 million. If the minimum PCP was further increased to 1 year the increase was an additional $247 million in inventory and $38.4 million in holding, ordering and stockout costs.

The AFAA report does not consider performance measures other than cost. It did not address any potential benefits of the increased minimum PCP policy. The simulation model did produce other performance measures which can be evaluated along with the cost increases to determine if the increase in minimum PCP was a good policy to adopt.

The primary benefit of an increase in the minimum PCP is a reduction in the number of buys required. In the third year the six month minimum policy resulted in 5286 fewer total buys of which 291 were large buys. A further reduction of 9608 buys, 315 large, resulted for a one year minimum. Using a weighted average of the ALC standard times to process large and small buys, 32.04 and 20.28 standard manhours (18), the three to six month change equates to a reduction of 110,622 manhours or 64 personnel equivalents using the AFLC standard of 1743.6 productive hours per person per year (6:21).

The increased PCP policy has drawbacks other than the increased inventory and increased implied costs. In the long run the amount of material in long supply increases. Initially more dollars are required and more backorders are generated although the difference between policies in these areas becomes insignificant in the third year.

Even with the additional information provided by this study, there is no easy answer to the question, "Is it a good policy to adopt an increased minimum PCP policy?" The answer depends on the criteria used to define "good." The AFAA study defined good in terms of minimizing holding, ordering and stockout costs, and the value of the average inventory. DOD specifies that the system is to minimize costs subject to a time-weighted, essentiality-weighted constraint on backorders. In a letter addressing the AFAA report, the Deputy Assistant Secretary of the Air Force (Logistics and Communications) stated:

> Existing EOQ formulae do not consider the readiness benefits of having a higher average inventory on hand, nor do they reflect the likely price breaks that would accrue from buying larger quantities in more economic production runs [21:1].

From this point of view "good" must consider the effect of EOQ policies on the operational mission of the forces that the EOQ items support and on the defense industrial base, factors not included in EOQ theory or formulae. In the letter requesting approval to change from the three month to the six month minimum policies, AFLC offered several reasons for the change. The change was expected to reduce the number of buy actions by approximately 7000 which would compensate for manning reductions. The letter stated, "The outlook for manning is such that we expect continued reductions in the personnel available to do the buying job" (16:1). The change was expected to reduce

repetitive buys, buys where contractors are asked to quote prices for the next buy before production of the previous buys had begun. Referring to repetitive buys the letter stated, "This not only denies economics of scale in ordering, but projects an image of uneconomic operation by the Air Force" (16:2). These reasons provide still more ideas to be included in the concept of "good."

This study cannot identify which is the best policy. There is no universal best policy. The judgement of the evaluator plays too big a factor in determining best. It is this researcher's hope, that this study has provided tangible evidence which policy makers in AFLC can combine with the intangible and political factors at their disposal to choose a policy which will support the nation's defense goals.

Recommendations for Further Study

During this research several factors were encountered which could affect the desirability of choosing one EOQ management policy over another, but which could not be investigated during this study. Further research in these areas could lead to policy modifications which would lead to providing better support at lower cost.

One potentially profitable research area is item migration. In a study of the behavior of items at the Defense Electronics Supply Center (DESC), Smith and Gumbert

found that the migration of items between demand categories was extensive. As an example, in their sample of items in a medium demand category only "1/3 of the original number were still medium after two years" (25:SMITH4). The implication of this finding is that the demand for two thirds of the items is either going up or down as a purchase is being made. By the time the purchase is delivered the quantity purchased will no longer be correct. If demand was going up, too little was ordered and if demand was going down, too much was ordered. Ordering too little results in extra buys being made and ordering too much results in higher inventory carrying costs and increased probabilities of wasting money on items that will never be used. A similar study of AFLC's EOQ items could determine if a similar phenomena exits and could result in procedures for identifying and compensating for this migration.

Another area for further research is in the area of lead-time demand. Better prediction of lead-time demand can result in fewer stockouts and lower costs. If the lead-time demand could be predicted more accurately, the reorder level could be established to prevent stockouts while minimizing safety level requirements. The exact determination of lead-time demand is impossible, but better lead-time demand determination could result in improved support at lower cost. The lead-time demand is made up two components, the length of the lead-time and the demand rate. Demand and

demand patterns have received some attention over the years, and although there is room for improvement in demand forecasting techniques, procedures for estimating demand are contained in current procedures. The second component of the lead-time demand is the length of the lead-time. Little study has been done in this area even though it is an area which could produce significant results. Currently the lead-time encountered on the last buy or an item manager "estimate" is used in EOQ calculations (7:1-10, 1-11). The lead-time for the last buy may or may not reflect the lead-time for the next buy. The DESC study showed that the lead-time to make a buy increased as an item migrated to higher demand value categories (25). If this same phenomena exists in AFLC, and it seems reasonable to assume it does, the lead-time for the last buy is not a good estimate of the lead-time for the next buy. A method of better forecasting the lead-time could greatly improve EOQ calculations and the support provided by the system.

Lead-time affects the system in another way. Money must be made available for the purchase of an item at the beginning of the lead-time to insure that it will be available when the item is delivered. This money is included in the total tied up in the EOQ system, but is not being used to support system goals. As the lead-time for the delivery of the items is increased the amount of money tied up in the lead time increases. Increasing the PCP, in

the long run, did not require more money for purchases each year, but it did increase the number of large buys. Large buys require more lead-time than small buys leading to the conclusion that increased PCPs require a larger investment in lead-time requirements. A study to determine the significance of the increased lead-time would be useful.

While this study was being made AFLC again changed its minimum PCP policy. A one year minimum PCP policy was established for items with a stable demand history as determined by a Kendall test. The simplistic model was run using the EOQs and reorder levels produced by the D062 system after this change had been implemented. The number of large buys was slightly less than the number required by the twelve month policy. The number of total buys fell between the number required by the six and twelve month minimum policies as did the number of commit dollars. A more complete evaluation of the new policy should be performed. One way to accomplish this evaluation would be to redesign EOQSIM to accommodate the Kendall test and then to perform comparative simulations.

Appendix A: FORTRAN Code for the Simplistic Model

```
C  PROGRAM SIM.OC UPDATED 7 AUGUST 1984
C*****************************************************************
C
C       VARIABLE DIRECTORY
C
*******************************************************************
C
C       COMDOL(YR,PLCY) DOLLARS SPENT ON FOR PURCHASE OF ITEMS
C       YR              SEQUENTIAL YEAR FROM 1 TO 10
C       PLCY            THE MINIMUM PCP POLICY USED 1=0YR, 2=.25YR,
C                       3=.5YR, 4=1YR, 5=NOT AFFECTED BY MINIMUM PCP
C       TOTCOM(PLCY)    THE TOTAL DOLLARS FOR EACH POLICY OVER TEN YEARS
C       NRBUY(SIZE,PLCY)THE NUMBER OF LARGE AND SMALL BUYS FOR EACH PLCY
C       SIZE            THE SIZE OF A BUY UNDER $19500 = 1, OVER = 2
C          (CATEOQ,PLCY)THE NUMBER OF ITEMS IN 13 EOQ SIZE CATEGORIES
C       CATEOQ          THE SIZE OF THE EOQ BROKEN DOWN INTO 13 CATEGORIES
C                       OF SIZE .25YR RANGING FROM 0 TO 3
C       ALC             TWO LETTER ALC CODE*
C       ACTPRC          ACTUAL UNIT PRICE*
C       ASOH            ASSETS ON HAND*
C       ASAD            ASSETS ADDITIVE*
C       ASDS            ASSETS DEPOT SUPPLY*
C       ASB             ASSETS ON HAND PURPOSE CODE B*
C       ASIT            ASSETS IN TRANSIT*
C       ASMIC           ASSETS MAINTENANCE INVENTORY CENTER*
C       ASUS            ASSETS UNSERVICEABLE*
C       ASDI            ASSETS DUEIN*
C       COND            CONDEMNATION FACTOR*
C       ASTOT           TOTAL ASSETS
C       PPR             PLANNED PROGRAM RATIO*
C       MDR             MONTHLY DEMAND RATE*
C       PMDR            PROGRAMMED MONTHLY DEMAND RATE*
C       EOQYR           EOQ YEARS*
C       SL              SAFETY LEVEL*
C       ALTD            ADMINISTRATIVE LEAD TIME IN DAYS*
C       PLTD            PRODUCTION LEAD TIME IN DAYS*
C       LEADTI          TOTAL LEAD TIME IN DAYS
C       ROL             REORDER LEVEL*
C       ROL1            REORDER LEVEL LESS THE SAFETY LEVEL
C       MAD             MEAN ABSOLUTE DEVIATION*
C       ARS             AVERAGE REQUISITION SIZE*
C       PAR             PROGRAMMED ANNUAL RATE
C       DAYDEM          DAILY DEMAND RATE
C       ALCHC           ALC HOLDING COST
C       ALCOC(SIZE)     ALC ORDERING COST
C       BADALC          COUNTER FOR RECORDS BAD ALC CODES
C       MINPCP          MINIMUM PROCUREMENT CYCLE PERIOD IN YEARS
C       ADD             ANNUAL DOLLAR DEMAND
```

```
C       THETA           STANDARD DEVIATION OF THE DEMAND
C       Q               ECONOMIC ORDER QUANTITY IN UNITS
C       K               NUMBER OF STANDARD DEVIATIONS TO INCLUDE
C                       IN THE SAFETY LEVEL
C       BUYDOL          DOLLAR VALUE OF AN EOQ PURCHASE
C       BUYDAY          DAY ON WHICH THE NEXT PURCHASE WILL BE MADE
C       CYCDAY          LENGTH OF AN EOQ CYCLE IN DAYS
C       INBUY           DOLLAR VALUE OF AN INITIAL PURCHASE IF
C                       THE INITIAL ON HAND QTY IS BELOW THE ROL
C       NRREC           A COUNTER FOR THE NUMBER OF RECORDS READ
C       ZRODEM          A COUNTER FOR THE NUMBER OF ITEMS WITH
C                       ZERO DEMAND
C       ZROEOQ         A COUNTER FOR THE NUMBER OF RECORDS WITH
C                      ZERO EOQYRS
C       *              INDICATES DATA ELEMENTS READ FROM THE INPUT TAPE
C
**********************************************************************
C
 INTEGER NUM(13,5),BADALC,PROC,NRBUY(11,5,2),CATEOQ,BUYYR,BUYSIZE
 INTEGER TOSMBY(5),TOLGBY(5)
 INTEGER NCHNG(5,12),YR,SIZE,LEADTI,NRREC,ZROEOQ
 INTEGER PLCY,ZRODEM,ASOH,ASAD,ASDS,ASB,ASIT,ASMIC,ASUS
 INTEGER ASDI,ASTOT,ALT,PLT,SL,ROL,ALTD,PLTD,ISF,NEW,ROL1
 REAL COMDOL(11,5), SQRT2,COND,PPR,MDR,PMDR,EOQYR,MAD,ARS
 REAL PAR,DAYDEM,ALCHC,ALCCST,MINPCP,ADD,THETA,Q,K,LAM,BUYDOL
 REAL BUYDAY,CYCDAY,TOTCST(5),ACTPRC,ALCOC(2),MIN,MAX
 CHARACTER ALC*2,ASITS*1,CONDS*1,MDRS*1,PMDRS*1,ROLS*1
 CHARACTER A*439,ALCCD*2
 COMMON /CHNG/ A,NCHNG
 COMMON /BOTH/ ACTPRC,ROL
 COMMON/BUYSUB/EOQYR,PAR,ASTOT,DAYDEM,COMDOL,NRBUY,NUM
 COMMON/ROLSUB/PPR,MAD,LEADTI,ALCHC,Q,LAM,ARS,ROL1,SQRT2,
&PMDR
C  DATA ALCCD/'OC'/,LAM/565./,ALCHC/.16/,ALCOC/376.05,766.69/
C DATA ALCCD/'OO'/,LAM/465./,ALCHC/.18/,ALCOC/505.30,865.10/
C DATA ALCCD/'SA'/,LAM/580./,ALCHC/.17/,ALCOC/345.54,608.30/
  DATA ALCCD/'SM'/,LAM/740./,ALCHC/.22/,ALCOC/446.45,577.64/
C DATA ALCCD/'WR'/,LAM/650./,ALCHC/.17/,ALCOC/381.04,575.91/
 BADALC=0
 NRREC=0
 ZRODEM=0
 ZROEOQ=0
 SQRT2=SQRT(2)
 DO 801 PLCY=1,5
 DO 802 YR=1,11
 COMDOL(YR,PLCY)=0
 NRBUY(YR,PLCY,1)=0
 NRBUY(YR,PLCY,2)=0
  802 CONTINUE
 DO 803 CATEOQ=1,13
 NUM(CATEOQ,PLCY)=0
  803 CONTINUE
```

```
 TOTCST(PLCY)=0
  801 CONTINUE
  1 READ(10,899,END=999) A
 DECODE(A,900) ALC,ACTPRC,ASOH,ASAD,ASDS,ASB,ASIT,ASITS,ASMIC,
&ASUS,ASDI,COND,CONDS,ALT,PLT,PPR,MDR,MDRS,PMDR,PMDRS,EOQYR,SL,
&ALTD,PLTD,ROL,ROLS,ISF,MAD,ARS
 CALL CHANGE(ASITS,NEW,1)
 ASIT=(ASIT*10)+NEW
 CALL CHANGE(CONDS,NEW,2)
 COND=((COND*10)+NEW)/100
 CALL CHANGE(MDRS,NEW,3)
 MDR=((MDR*10)+NEW)/100
 CALL CHANGE(PMDRS,NEW,4)
 PMDR=((PMDR*10)+NEW)/100
 CALL CHANGE(ROLS,NEW,5)
 ROL=(ROL*10)+NEW
 PPR=PPR/10
 EOQYR=EOQYR/100
 NRREC=NRREC+1
C CHECK FOR ALC CODE
 IF (ALC.EQ.ALCCD) GO TO 2
 BADALC=BADALC+1
 GO TO 1
  2 CONTINUE
C CHECK FOR ZERO DEMAND
 IF (PMDR.NE.0) GO TO 3
 ZRODEM=ZRODEM+1
 GO TO 1
  3 CONTINUE
 IF (EOQYR.GT.0.) GO TO 5
 ZROEOQ=ZROEOQ+1
 GO TO 1
 5 CONTINUE
C  CALCULATE  BASIC  VALUES  THAT WILL  BE  USED  IN  FUTURE CALCULATIONS
 ROL1=ROL-SL
 LEADTI=ALT+PLT
 PAR=PMDR*12
 DAYDEM=PAR/365.25
 SIZE=1
 IF ((PAR*ACTPRC).GE.50000.) SIZE=2
 ASTOT=ASOH+ASAD+ASDS+ASB+ASIT+ASMIC+INT(ASUS*(1.-COND))+ASDI
C  CHECK  TO  SEE IF ANY OF THE MINIMUM  PCP  POLICIES  WILL
C AFFECT THIS ITEM.
 IF (EOQYR.LE.1) GO TO 4
 CALL BUY(5)
 GO TO 1
  4 CONTINUE
C     CALCULATE ACTUAL EOQ
 SIZE=1
 IF ((PAR*ACTPRC).GE.50000.) SIZE=2
 EOQYR=SQRT((2*ALCOC(SIZE))/(ALCHC*ACTPRC*PAR))
C ESTABLISH 1MO MINIMUM FOR COMPUTATIONAL PRACTICALITY
```

```
 IF (EOQYR.LE.0.083) EOQYR=0.083
 Q=EOQYR*PAR
 CALL ROLVL(DUMMY)
  6 CONTINUE
C ACCUMULATE COSTS FOR 1 MO MINIMUM PCP (POLICY 1)
 CALL BUY(1)
C ESTABLISH .25 AS MINIMUM PCP AND ADJUST ROL ACCORDINGLY.
 IF (EOQYR.GT..25) GO TO 9
 EOQYR=.25
 Q=.25*PAR
 CALL ROLVL(DUMMY)
  9 CONTINUE
C ACCUMULATE COSTS FOR .25 YR MINIMUM PCP (POLICY 2)
 CALL BUY(2)
C ESTABLISH .5 AS MINIMUM PCP AND ADJUST ROL ACCORDINGLY.
 IF (EOQYR.GT.0.5) GO TO 19
 EOQYR=.5
 Q=.5*PAR
 CALL ROLVL(DUMMY)
  19 CONTINUE
C ACCUMULATE COSTS FOR .5 YR MINIMUM PCP (POLICY 3)
 CALL BUY(3)
C ESTABLISH 1 YR AS MINIMUM PCP AND ADJUST ROL ACCORDINGLY.
 EOQYR=1
 Q=PAR
 CALL ROLVL(DUMMY)
C ACCUMULATE COSTS FOR 1 YR MINIMUM PCP (POLICY(4))
 CALL BUY(4)
C RETURN TO BEGINNING TO GET ANOTHER ITEM.
 GO TO 1
  999 CONTINUE
C END OF CALCULATIONS BEGINNING OF OUTPUT
C WRITE HEADING
 WRITE (6,901) ALC
C WRITE SEPARATE TOTALS
 WRITE (6,902)
 DO 11 YR=1,11
 IYR=YR-1
 WRITE (6,903) IYR,(COMDOL(YR,PLCY),PLCY=1,5)
 DO 11 PLCY=1,5
 TOTCST(PLCY)=TOTCST(PLCY)+COMDOL(YR,PLCY)
 COMDOL(YR,PLCY)=COMDOL(YR,PLCY)+COMDOL(YR,5)
  11 CONTINUE
C WRITE TEN YEAR COST FOR EACH POLICY
 WRITE (6,904) (TOTCST(PLCY),PLCY=1,5)
 DO 12 PLCY=1,4
 TOTCST(PLCY)=TOTCST(PLCY)+TOTCST(5)
  12 CONTINUE
C WRITE ACCUMULATED TABLE
 WRITE (6,905)
 DO 13 YR=1,11
 IYR=YR-1
```

```
 WRITE (6,906) IYR,(COMDOL(YR,PLCY),PLCY=1,4)
  13 CONTINUE
 WRITE (6,907) (TOTCST(PLCY),PLCY=1,4)
C WRITE OTHER STATISTICS
 WRITE(6,913)
C WRITE BUYSIZE TABLE
 DO 15 YR=1,11
 IYR=YR-1
 WRITE (6,914) IYR,(NRBUY(YR,PLCY,1),NRBUY(YR,PLCY,2),
&PLCY=1,5)
 DO 15 PLCY =1,5
 TOSMBY(PLCY)=TOSMBY(PLCY)+NRBUY(YR,PLCY,1)
 TOLGBY(PLCY)=TOLGBY(PLCY)+NRBUY(YR,PLCY,2)
 NRBUY(YR,PLCY,1)=NRBUY(YR,PLCY,1)+NRBUY(YR,5,1)
 NRBUY(YR,PLCY,2)=NRBUY(YR,PLCY,2)+NRBUY(YR,5,2)
 15 CONTINUE
 WRITE (6,915) (TOSMBY(PLCY),TOLGBY(PLCY),PLCY=1,5)
 DO 16 PLCY=1,4
 TOSMBY(PLCY)=TOSMBY(PLCY)+TOSMBY(5)
 TOLGBY(PLCY)=TOLGBY(PLCY)+TOLGBY(5)
 16 CONTINUE
 WRITE (6,916)
 DO 17 YR=1,11
 IYR=YR-1
 WRITE (6,917) IYR,(NRBUY(YR,PLCY,1),NRBUY(YR,PLCY,2),
&PLCY=1,4)
 17 CONTINUE
 WRITE (6,918) (TOSMBY(PLCY),TOLGBY(PLCY),PLCY=1,4)
 WRITE (6,909) BADALC,NRREC,ZRODEM
 MAX=0
 WRITE (6,910)
 DO 14 CATEOQ=1,13
 MIN=MAX
 MAX=.25*CATEOQ
 WRITE (6,911) MIN,MAX,(NUM(CATEOQ,PLCY),PLCY=1,5)
  14 CONTINUE
 WRITE (6,912) ((NCHNG(I,J),J=1,12),I=1,5)
**************************************************************************
C
C                              FORMATS
C
**************************************************************************
  899 FORMAT(A439)
  900 FORMAT(A2,61X,F9.2,94X,4I7,I6,A1,3I7,21X,F2.0,A1,2I2,2X,F4.2,
&2(F8.0,A1),F3.0,35X,I7,I3,I4,7X,I6,A1,35X,I6,F10.2,F6.1)
  901 FORMAT ('1',24X,'COMMITTMENT DOLLARS FOR VARIOUS MINIMUM
&PCP POLICIES'//11X,'BASED ON DEC 83 DATA FROM ',A2,'-ALC
&STRAIGHT LINED FOR TEN YEARS INTO THE FUTURE'/////)
  902 FORMAT (35X,'COMMITTED DOLLARS'//2X,'YEAR',35X,'POLICY'/
&13X,'1MO MIN PCP',5X,'.25 YR MIN PCP',5X,'.50 YR MIN PCP',
&7X,'1 YR MIN PCP',9X,'UNAFFECTED'/)
  903 FORMAT (4X,I2,5(4X,F15.0))
```

```
  904 FORMAT (6X,5(4X,F15.0))
  905 FORMAT (//28X,'COMMITTED DOLLARS (CONSOLIDATED)'/
&/2X,'YEAR',35X,'POLICY'/
&13X,'1MO MIN PCP',5X,'.25 YR MIN PCP',5X,'.50 YR MIN PCP',
&7X,'1 YR MIN PCP'/)
  906 FORMAT (4X,I2,4(4X,F15.0))
  907 FORMAT (6X,4(4X,F15.0))
  909 FORMAT (///2X,'THERE WERE ',I6,' RECORDS WITH UNRECOGNIZED
&ALC CODES.'/2X,'THERE WERE ',I6,' RECORDS READ.'/2X,'THERE
&WERE ',I6,' RECORDS WITH A PROGRAMMED MONTHLY DEMAND OF ZERO.'/)
  910 FORMAT ('1',2X,'EOQYR CAT',7X,'NUMBER PER CATEGORY FOR EACH '
&'POLICY'/3X,'GE ',3X,'LT ',5X,'0 MIN',3X,'.25 MIN',3X,
&'.50 MIN',5X,'1 MIN',7X,'ALL'/)
  911 FORMAT (2(2X,F4.2),5(4X,I6))
  912 FORMAT(///2X,'VARIABLE',5X,'A/J',3X,'B/K',3X,'C/L',3X,'D/M',3X,
&'E/N',3X,'F/O',3X,'G/P',3X,'H/Q',3X,'I/R',3X,'+/^',1X,'OTHER',
&3X,'NUM'/5X,'ASITS',2X,(11(1X,I5)),1X,I6/5X,'CONDS',2X,(11(1X,I5)),
&1X,I6/
&5X,'MDRS ',2X,(11(1X,I5)),1X,I6/5X,'PMDRS',2X,(11(1X,I5)),1X,I6/
&5X,'ROLS ',2X,(11(1X,I5)),1X,I6/)
 913 FORMAT('1',36X,'TOTAL BUYS'//9X,'1MO MIN PCP',4X,
&'3MO MIN PCP',5X,'AFLC PLCY',6X,'1YR MIN',6X,
&'UNAFFECTED'/2X,'YEAR',2X,'SMALL',2X,'LARGE',
&4(3X,'SMALL',2X,'LARGE')/)
 914 FORMAT(4X,I2,1X,I6,1X,I6,4(2X,I6,1X,I6))
 915 FORMAT(5X,5(2X,'------ ------')/2X,'TOT',
&5(2X,I6,1X,I6))
 916 FORMAT(///28X,'TOTAL BUYS (CONSOLIDATED)'/
&/9X,'1MO MIN PCP',4X,
&'3MO MIN PCP',5X,'AFLC PLCY',6X,'1YR MIN'
&/2X,'YEAR',2X,'SMALL',2X,'LARGE',
&3(3X,'SMALL',2X,'LARGE')/)
 917 FORMAT(4X,I2,1X,I6,1X,I6,3(2X,I6,1X,I6))
 918 FORMAT(5X,4(2X,'------ ------')/2X,'TOT',
&4(2X,I6,1X,I6))
 STOP
 END
C
***********************************************************************
***********************************************************************
C
C                       SUBROUTINE BUY
C
***********************************************************************
C
 SUBROUTINE BUY(PLCY)
 COMMON /BOTH/ ACTPRC,ROL
 COMMON /BUYSUB/EOQYR,PAR,ASTOT,DAYDEM,COMDOL,NRBUY,NUM
 REAL EOQYR,PAR,ACTPRC,BUYDOL,INBUY,COMDOL(11,5),DAYDEM
 REAL BUYDAY,CYCDAY
 INTEGER BUYSIZ,ASTOT,ROL,NRBUY(11,5,2),PLCY
 INTEGER CATEOQ,NUM(13,5),BUYYR
```

```
C CORRECT FOR INITIAL INVENTORY LESS THAT THE REORDER POINT.
 BUYDOL=EOQYR*PAR*ACTPRC
 BUYSIZ=2
 IF (BUYDOL.LT.25000) BUYSIZ=1
C DETERMINE DATE OF FIRST BUY
 BUYDAY=(ASTOT-ROL)/DAYDEM
C DETERMINE THE NUMBER OF DAYS BETWEEN BUYS
 CYCDAY=EOQYR*365.25
C CHECK TO SEE IF A BUY IS OVERDUE
 IF (BUYDAY.GT.0) GO TO 502
 INBUY=BUYDOL+((ROL-ASTOT)*ACTPRC)
C ACCUMULATE DOLLARS SPENT FOR THE FIRST BUY
 COMDOL(1,PLCY)=COMDOL(1,PLCY)+INBUY
 BUYDAY=CYCDAY
 IF (INBUY.LT.25000) GO TO 503
 NRBUY(1,PLCY,2)=NRBUY(1,PLCY,2)+1
 GO TO 502
  503 NRBUY(1,PLCY,1)=NRBUY(1,PLCY,1)+1
  502 CONTINUE
 CATEOQ=(EOQYR/.25)+1
 NUM(CATEOQ,PLCY)=NUM(CATEOQ,PLCY)+1
C ACCUMULATE ANNUAL EXPENDITURES FOR THE ITEM OVER A TEN YEAR PERIOD
  1 IF (BUYDAY.GT.3652) RETURN
 BUYYR=(BUYDAY/365.25)+2
C COUNT THE NUMBER OF LARGE OR SMALL BUYS
 NRBUY(BUYYR,PLCY,BUYSIZ)=NRBUY(BUYYR,PLCY,BUYSIZ)+1
C ACCUMULATE DOLLARS SPENT
 COMDOL(BUYYR,PLCY)=COMDOL(BUYYR,PLCY)+BUYDOL
C ESTABLISH NEXT PURCHASE DATE
 BUYDAY=BUYDAY+CYCDAY
 GO TO 1
 END
**********************************************************************
C
C                        SUBROUTINE ROLVL
C
**********************************************************************
C
 SUBROUTINE ROLVL(DUMMY)
 COMMON /BOTH/ ACTPRC,ROL
 COMMON /ROLSUB/PPR,MAD,LEADTI,ALCHC,Q,LAM,ARS,ROL1,SQRT2,
&PMDR
 REAL PPR,MAD,ALCHC,ACTPRC,LAM,THETA,K,Q,SQRT2,ARS,PMDR
 INTEGER ROL,LEADTI,ROL1
 EADTI=FLOAT(LEADTI)
 THETA=(PPR**.85)*.5945*MAD*(.82375+(.42625*EADTI))
 IF (THETA.LE.0.) THETA=.0001
 K=(-.707)*ALOG((2*SQRT2*ALCHC*Q*ACTPRC)/((LAM*1/ARS)*THETA*
&(1-EXP(((-SQRT2)*Q)/THETA))))
 SL=K*THETA
 SLMAX=EADTI*PMDR
 SLMAXI=3.*THETA
```

```
      IF(SL.GT.SLMAX) SL=SLMAX
      IF (SL.GT.SLMAXI) SL=SLMAXI
      IF (SL.LT.0) SL=0
      ROL=ROL1+IFIX(SL)+1
      RETURN
      END
*****************************************************************
C
C           SUBROUTINE  CHANGE
C
*****************************************************************
C
      SUBROUTINE CHANGE(IN,OUT,I)
      COMMON /CHNG/ A,NCHNG
      CHARACTER A*439,IN
      INTEGER NCHNG(5,12),OUT
      IF (IN.LT."0".OR.IN.GT."9") GO TO 11
      DECODE (IN,900) OUT
      NCHNG(I,12)=NCHNG(I,12)+1
      RETURN
   11 CONTINUE
      IF(IN.EQ."A".OR.IN.EQ."J") GO TO 1
      IF(IN.EQ."B".OR.IN.EQ."K") GO TO 2
      IF(IN.EQ."C".OR.IN.EQ."L") GO TO 3
      IF(IN.EQ."D".OR.IN.EQ."M") GO TO 4
      IF(IN.EQ."E".OR.IN.EQ."N") GO TO 5
      IF(IN.EQ."F".OR.IN.EQ."O") GO TO 6
      IF(IN.EQ."G".OR.IN.EQ."P") GO TO 7
      IF(IN.EQ."H".OR.IN.EQ."Q") GO TO 8
      IF(IN.EQ."I".OR.IN.EQ."R") GO TO 9
      IF(IN.EQ."+".OR.IN.EQ."^") GO TO 10
      OUT=0
      NCHNG(I,11)=NCHNG(I,11)+1
      RETURN
    1 OUT=1
      NCHNG(I,1)=NCHNG(I,1)+1
      RETURN
    2 OUT=2
      NCHNG(I,2)=NCHNG(I,2)+1
      RETURN
    3 OUT=3
      NCHNG(I,3)=NCHNG(I,3)+1
      RETURN
    4 OUT=4
      NCHNG(I,4)=NCHNG(I,4)+1
      RETURN
    5 OUT=5
      NCHNG(I,5)=NCHNG(I,5)+1
      RETURN
    6 OUT=6
      NCHNG(I,6)=NCHNG(I,6)+1
      RETURN
```

```
 7 OUT=7
NCHNG(I,7)=NCHNG(I,7)+1
RETURN
 8 OUT=8
NCHNG(I,8)=NCHNG(I,8)+1
RETURN
 9 OUT=9
NCHNG(I,9)=NCHNG(I,9)+1
RETURN
 10 OUT=0
NCHNG(I,10)=NCHNG(I,10)+1
RETURN
900 FORMAT(I1)
END
```

Appendix 8: Number of Buys Required by Various Minimum PCP Policies

YR	POLICY			
	1 Mo Min (Small/Large Total)	3 Mo Min (Small/Large Total)	6 Mo Min (Small/Large Total)	1 Yr Min (Small/Large Total)
Initial	17798/ 3465 21263	17798/ 3459 21257	17579/ 3560 21139	16485/ 4124 20609
1	51443/ 10497 61940	51402/ 7110 58512	44179/ 5639 49818	30603/ 4996 35599
Initial + 1	69241/ 13962 83203	69200/ 10569 79769	61758/ 9199 70957	47088/ 9120 56208
2	87026/ 16213 103239	86925/ 12049 98974	77754/ 10351 88105	58862/ 9997 68859
3	98802/ 17436 116238	98681/ 12965 111646	88199/ 11132 99331	66842/ 10655 77497
4	114350/ 17823 132173	114214/ 13321 127535	103485/ 11447 114932	80877/ 10946 91823
5	112687/ 17949 130636	112552/ 13435 125987	101532/ 11572 113104	78506/ 11074 89580
6	115481/ 18024 133505	115343/ 13469 128812	104267/ 11643 115910	80771/ 11156 91927
7	125949/ 18081 144030	125801/ 13543 139344	114619/ 11680 126299	90909/ 11211 102120
8	121511/ 18107 139618	121370/ 13571 134941	110117/ 11703 121820	86359/ 11246 97605
9	123368/ 18130 141498	123227/ 13559 136786	111986/ 11720 123706	88070/ 11269 99339
10	130891/ 18110 149001	130753/ 13568 144321	119522/ 11715 131237	95403/ 11277 106680

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Thesis Chairman: Palmer W. Smith, Lieutenant Colonel, USAF

Block 18: Logistics Planning Stockage Policies, Procurement Cycle Periods, PCP, Stock Fund Budget

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Policy decisions concerning the Air Force economic order quantity (EOQ) item management system affect thousands of items, billions of dollars, and the readiness of the Air Force. This ~~study~~ thesis was initiated as a result of a March 1983 Air Force Audit Agency report finding potential waste of monies because of deviation from normal procurement cycle periods (PCPs). It evaluates different PCP policies and their affect on several system performance measures for the Air Force consumable item management system. The evaluation was performed using simulation models and actual Air Force item data. The results support the audit report showing increased cost and investment as a result of larger minimum PCPs. In the first year, larger minimum PCP policies require more stock fund dollars to fund inventory growth, approximately $1211M, $1311M, and $1560M for the 3, 6, and 12 month policies respectively. After the inventory reaches its new level the differences in the annual commit dollar requirements between policies becomes insignificant. The increased inventories cause the differences in implied costs between policies to become significant with larger PCPs having higher costs, approximately $547M, $570M, and $608M. The larger PCPs and larger inventories also result in larger excesses. The customer support provided by the three policies is not significantly different, although larger PCPs produce more backorders during the transition to the new policy. Fewer procurement actions are required for larger minimum PCPs, approximately 61K, 56K and 46K respectively, although in the first year larger PCPs require a few more large buys. Fewer buys require less manpower and larger buys provide increased opportunity for quantity discounts. The choice of a "best" policy depends on the criteria of the policy maker and on political and practical considerations in addition to the factors discussed in this study.